

**Toughened nylon, the process of preparing it and its use****10/553019**Technical scope

This invention relates to a toughened nylon and its preparation and application; 5 namely a toughened nylon prepared by matrix nylon that is toughened by long-chain nylon and its preparation processes and application.

Technical background

Generally nylon is toughened by rubber, such as ethylene-propylene rubber, 10 terco-ethylene-propylene rubber, butadiene-acrylonitrile rubber, butadiene-styrene rubber, or thermoplastic elastomer, such as styrene-butadiene-styrene copolymer (SBS), styrene-ethylene-butadiene-styrene copolymer (SEBS), ethylene-vinyl acetate copolymer (EVA) and ethylene acrylic acid copolymer (EAA). However as the compatibility of these components with matrix nylon is very poor, a solubilizer 15 must be added, such as elastomers grafted with maleic anhydride (for example, polyethylene-g- maleic anhydride (E-g-MAH), thermoplastic elastomer-g- maleic anhydride (TPE-g-MAH) and others). The nylon prepared by the above process is an alloy-polymer in morphology and the preparation process is rather complicate.

20 Casting nylon has high molecular weight and excellent mechanical performance. However as large-size article formed by casting process often tends to break due to poor toughness and also has high notch sensitivity, modification is necessary. In prior art the toughening method of casting nylon-6 is mainly copolymerization with dodecanolactam or modification with rubber component. 25 Therefore the modifying agents adopted are mainly amino capped polyoxyethylene oxide, polypropylene oxide or their copolymers, amino capped liquid polybutadiene or butadiene-acrylonitrile rubber. For example, in U.S. Patent 4,882,382, 4,994,524 and 5,189,098 casting nylon is toughened by core-shell polymer. An aqueous dispersion of polymer consisting of elastomer core and hard thermoplastic shell is 30 prepared, and the aqueous dispersion is mixed with the aqueous solution of hexanolactam to obtain a dispersion after dehydrating. Then such dispersion,

catalyst and hexanolactam are polymerized to obtain Nylon-6 toughened by rubber, in which the content of core-shell polymer is generally over 10%. The preparation process of said toughening agent is complicate and difficult in operation.

5       Nylon prepared by hydrolysis condensation polymerization or screw reacting extrusion is mainly toughened by rubber or reactive toughening agent with low molecular weight. Or resin prepared hereby is toughened by rubber or elastomer in screw extrusion process.

10      However in all said toughened nylons the rubber or thermoplastic elastomer do not dissolve in the lactam monomer of nylon, so that the rubber or elastomer exists in matrix nylon as a dispersed phase. The property of nylon depends on the extent of dispersed phase, and the crystallinity of nylon and the strength of article formed with said nylon exhibit a great reduction. Therefore it is difficult to toughen  
15     casting nylon successfully by rubber or thermoplastic elastomer as toughening agent.

#### Invention

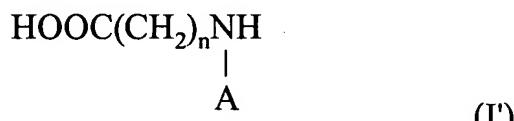
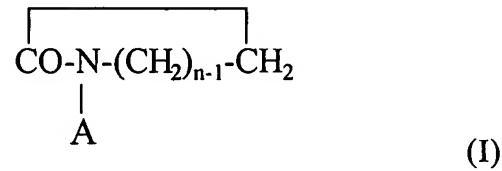
The present invention is directed to preparing a nylon that has reinforced  
20     toughness, in the preparation of which no solubilizer is needed and no dispersed phase that may reduce the strength of material made with this nylon occurs.

Another aspect of the invention is directed to providing a simple and easy operable process for the preparation of said toughened nylon.

25      And yet another aspect of the invention is directed to providing the application of said toughened nylon.

In this invention a toughened nylon that comprises a matrix nylon and a  
30     long-chain nylon is described. The matrix nylon is prepared by the homopolymerization or copolymerization of cyclic lactam monomers or their

corresponding amino acids. The structure of said cyclic lactam is represented by Formula (I) and the structure of amino acid is represented by (I').



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In Formula (I) and (I') A is H or alkyl with 1-8 carbon and  $3 \leq n \leq 11$ .

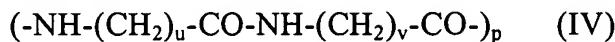
The long-chain nylon is selected from nylons that contain repeating units  
10 having structures represented by Formula (II), (III) or (IV).



In Formula (II) D is  $-(\text{CH}_2)_x-$ , in which H may be substituted with C<sub>1-4</sub> alkyl  
optionally ; E is  $-(\text{CH}_2)_y-$  or phenylene, in which H may be substituted with C<sub>1-4</sub>  
alkyl optionally;  $4 \leq x \leq 34$  and  $4 \leq y \leq 34$ .

15  $(-\text{NH}-(\text{CH}_2)_w\text{-CO-})_p \quad (\text{III})$

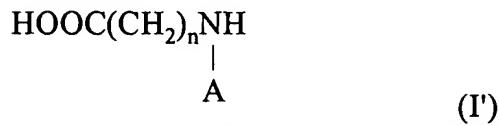
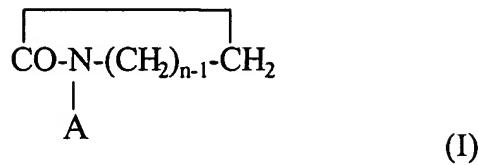
In Formula (III),  $7 \leq w \leq 34$ ;



In Formula (IV),  $5 \leq u \leq 34$ ,  $5 \leq v \leq 34$ , and  $u \neq v$ .

20 The proportion of said long-chain nylon in the total weight of toughened nylon  
is 2-45%. As the toughened nylon has very good interface combination, only one  
melting peak is detected with differential scanning calorimetry.

25 In the invention a toughened nylon that comprises a matrix nylon and a  
long-chain nylon is described. The matrix nylon is prepared by the  
homopolymerization or copolymerization of cyclic lactam monomers or their  
corresponding amino acids. The structure of said cyclic lactam is represented by  
Formula (I) and the structure of amino acid is represented by and (I').



In Formula (I) and (I') A is H or alkyl with 1-8 carbon and  $3 \leq n \leq 11$ .

5 The long-chain nylon is selected from nylons that contain repeating units having structures represented by Formula (II), (III) or (IV).

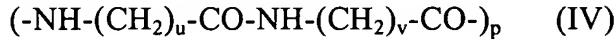


In Formula (II) D is  $-(\text{CH}_2)_x-$ , in which H may be substituted with C<sub>1-4</sub> alkyl optionally ; E is  $-(\text{CH}_2)_y-$  or phenylene, in which H may be substituted with C<sub>1-4</sub>

10 alkyl optionally;  $4 \leq x \leq 34$  and  $4 \leq y \leq 34$ .



In Formula (III),  $7 \leq w \leq 34$



In Formula (IV),  $5 \leq u \leq 34$ ,  $5 \leq v \leq 34$ , and  $u \neq v$ .

15

The said toughened nylon is prepared by the polymerization of said cyclic lactam monomer in the existence of said long-chain nylon as toughening agent. The proportion of said long-chain nylon used as toughening agent in the total weight of toughened nylon is 2-45%.

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In the technical program of this invention the optimized proportion of long-chain nylon in the total weight of toughened nylon is 6-25%. The cyclic lactam monomer is selected from one or more following monomers: butanolactam, pentanolactam, hexanolactam, heptanolactam, octanolactam, nonanolactam, 25 decanolactam, undecanolactam, dodecanolactam, N-methyl hexanolactam, N-n-octyl nonanolactam, N-t-butyl dodecanolactam; the corresponding amino acid is  $\omega$ -amino butanoic acid,  $\omega$ -amino pentanoic acid,  $\omega$ -amino hexanoic acid,  $\omega$ -amino heptnoic acid,  $\omega$ -amino octanoic acid,  $\omega$ -amino nonanoic acid,  $\omega$ -amino

decanoic acid,  $\omega$ -amino undecanoic acid or  $\omega$ -amino dodecanoic acid; the said long-chain nylon is selected from one or more following nylons: nylon-1010, nylon-1111, nylon-1212, nylon-1313, nylon-46, nylon-66, nylon-610, nylon-612, nylon-613, nylon-1011, nylon-1012, nylon-1213, nylon-8, nylon-9, nylon-11, 5 nylon-12, nylon-13, poly(telephthaloyl-2,2,4-trimethyl hexamethylene diamine), poly(3-t-butyl-hexanedioyl heptamethylene diamine), co-condensation nylon 6/7, co-condensation nylon 6/10, co-condensation nylon 6/12, co-condensation nylon 6/13, co-condensation nylon 10/11, co-condensation nylon 10/12, co-condensation nylon 12/13, nylon-6T and nylon-10T.

10

A preparation process of said toughened nylon is described in this invention, the steps of which are as follows: dissolve said long-chain nylon resin in said lactam monomer or its corresponding amino acid. The polymerization of said lactam monomer or its corresponding amino acid is carried out. The dissolution 15 step and the polymerization step may be conducted simultaneously. Or dissolve at first and then carry out polymerization in the solution obtained.

With regard to the preparation process of this invention, it is preferred that the said polymerization is carried out with one of such processes as casting, reacting 20 extrusion, hydrolysis polymerization or solid phase polymerization.

The steps of casting process are as follows: dissolve said long-chain nylon in melted cyclic lactam monomer or its corresponding amino acid; dehydrate; then add catalyst and dehydrate again, raise temperature to 120-200°C and add catalyst 25 promoter; immediately transfer into preheated mould and polymerize in an oven at 150-250°C to obtain toughened nylon.

The steps of reacting extrusion process are as follows: add and dissolve said long-chain nylon in cyclic lactam monomer or its corresponding amino acid in a 30 reactor; dehydrate in vacuum; add catalyst and continue to dehydrate in vacuum; add cyclic lactam monomer or its corresponding amino acid and catalyst promoter

in another reactor, dehydrating in vacuum. Add the contents of two reactors into an extruder for polymerization; set the temperature of polymerization section at 220-250°C and adjust screw speed so that the residence time of material in screw is 0.5-7 minutes. Toughened nylon is provided as extruded product.

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The steps of hydrolysis polymerization process are as follows: add said long-chain nylon resin to cyclic lactam monomer or its corresponding amino acid, heat and dissolve, add water and conduct hydrolysis polymerization at 200-250°C and 10-20 MPa, depressurize after 0.5-6 hours and dehydrate in vacuum, continue 10 polymerization for further increasing viscosity, and then toughened nylon is obtained.

The present invention also provides the application of said toughened nylon in the manufacture of gears, bearings, precise instrumental parts and automobile parts.

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In this present invention a toughen nylon is obtained by matrix nylon that is prepared by the homopolymerization or copolymerization of cyclic lactam and is toughened by long-chain nylon. This obtained nylon exhibits reinforced toughness, excellent tensile strength, breaking elongation and notched impact strength as well 20 good cold resistance as the reduction of toughness at -40°C is still acceptable. No solubilizer is needed in the process and there is not any dispersed phase in matrix nylon, which may reduce the strength of material and is well known in much prior art. As long-chain nylon is dissolvable in lactam monomer, the preparation of toughened nylon provided in this invention is easy and simple in operation, needing 25 no solubilizer or other means to improve the compatibility of toughening agent with matrix nylon.

#### Brief description of figures

Figure 1 is the electron microscope photo of product prepared with the 30 invention by adding 8% (wt.%, based on the total weight of toughened nylon) of nylon 1212 resin in hexanolactam monomer, at 30000 times of magnification.

Figure 2 is the electron microscope photo of product prepared with the invention by adding 10% (wt.%, based on the total weight of toughened nylon) nylon 1212 resin in hexanolactam monomer, at 4000 times of magnification.

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Figure 3 is the electron microscope photo of pure and non-toughened nylon 6 prepared with a prior art, at 10000 times of magnification.

10 Figure 4 is the deferential scanning calorimetry (DSC) spectrum of nylon 6 toughened by nylon 1212 with the invention.

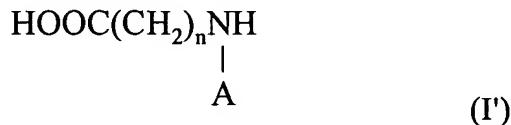
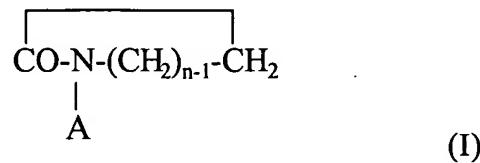
Figure 5 is the deferential scanning calorimetry (DSC) spectrum of the commixture of nylon 6 and nylon1212.

15 Figure 6 is the deferential scanning calorimetry (DSC) spectrum of pure nylon 6.

#### Details of implementation

The term “matrix nylon” in this invention refers to the toughened part of 20 toughened nylon, which is prepared by the homopolymerization or copolymerization of cyclic lactam monomer and their corresponding amino acid. The structure of said cyclic lactam is represented by Formula (I) and the structure of said amino acid is represented by Formula (I').

25



In Formula (I) and (I') A is H or alkyl with 1-8 carbon and  $3 \leq n \leq 11$ .

The said cyclic lactam monomers include butanolactam, pentanolactam, hexanolactam, heptanolactam, octanolactam, nonanolactam, decanolactam, undecanolactam, dodecanolactam, N-methyl hexanolactam, N-n-octyl nonanolactam and N-t-butyl dodecanolactam, but hexanolactam is preferred; the  
5 said corresponding amino acids include  $\omega$ -amino butanoic acid,  $\omega$ -amino pentanoic acid,  $\omega$ -amino hexanoic acid,  $\omega$ -amino heptanoic acid,  $\omega$ -amino octanoic acid,  $\omega$ -amino nonanoic acid,  $\omega$ -amino decanoic acid,  $\omega$ -amino undecanoic acid or  $\omega$ -amino dodecanoic acid. The matrix nylon may be prepared by the homopolymerization of any cyclic lactam monomer or its corresponding amino acid,  
10 such as nylon-4, nylon-5, nylon-6, nylon-7, nylon-8, nylon-9, nylon-10, nylon-11 and nylon-12. The matrix nylon may also be prepared by the copolymerization of any cyclic lactam monomer or its corresponding amino acid, such as co-condensation nylon 4/6 (which may be prepared by the condensation polymerization of  $\omega$ -amino butanoic acid and  $\omega$ -amino hexanoic acid),  
15 co-condensation nylon 6/10, co-condensation nylon 6/9 and co-condensation nylon 6/12.

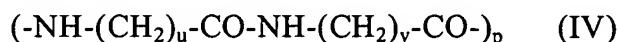
The term “long-chain nylon” in this invention refers to nylon in which the carbon atom number of main chain in repeated units is 8 at least, including the  
20 nylons containing repeated units represented by Formula (II), (III) and (IV).



In Formula (II) D is  $-(\text{CH}_2)_x-$ , in which H may be substituted with  $\text{C}_{1-4}$  alkyl optionally ; E is  $-(\text{CH}_2)_y-$  or phenylene, in which H may be substituted with  $\text{C}_{1-4}$  alkyl optionally;  $4 \leqslant x \leqslant 34$  and  $4 \leqslant y \leqslant 34$ .



In Formula (III),  $7 \leqslant w \leqslant 34$ ;



In Formula (IV)  $5 \leqslant u \leqslant 34$ ,  $5 \leqslant v \leqslant 34$ , and  $u \neq v$ .

30 The carbon atom number of main chain in the repeated units of long-chain nylon that is used as toughening agent in this invention should be 8 at least, or 10 is

preferred. The said long-chain nylon may be a nylon containing repeating units represented by Formula (II), (III) and (IV). The following nylons are preferred, such as nylon-1010, nylon-1111, nylon-1212, nylon-1313, nylon-46, nylon-66, nylon-610, nylon-612, nylon-613, nylon-1011, nylon-1012, nylon-1213,

5 poly(telephthaloyl-2,2,4-trimethyl hexamethylene diamine), poly(3-t-butyl-hexanedioyl heptamethylene diamine), nylon-8, nylon-9, nylon-11, nylon-12, nylon-13, co-condensation nylon 6/7, co-condensation nylon 6/10, co-condensation nylon 6/12, co-condensation nylon 6/13, co-condensation nylon 10/11, co-condensation nylon 10/12, co-condensation nylon 12/13, nylon-6T,

10 nylon-10T and their combinations. There is not any restriction for the molecular weight of long-chain nylon, but the long-chain nylon should be dissolvable in cyclic lactams or corresponding amino acids.

In this invention long-chain nylon is adopted as toughening agent to replace

15 rubber or thermoplastic elastomer in prior art. The advantage of long-chain nylon is to be dissolvable in nylon polymerized with cyclic lactam monomers or their corresponding amino acids, which may be either homopolymer or copolymer. As long-chain nylon and matrix nylon have similar structure containing amido bond, they have good compatibility with each other, namely good interface combination.

20 Meanwhile as the main chain of repeated units in long-chain nylon has at least 8 carbon atoms, the density of hydrogen bond, crystallization procedure and crystallinity are changed accordingly. Hence the toughness of nylon is greatly reinforced by the unique structure. The adding amount of long-chain nylon depends on different processes and performance requirements, and it usually is 2-45% of

25 total weight of toughened nylon, and 6-25% is preferred.

The toughened nylon mentioned in this invention may be prepared by a simple practicable process, such as anion initiate polymerization of casting monomer, single (double) screw reacting extrusion and hydrolysis condensation

30 polymerization.

In casting process long-chain nylon used as toughening agent is directly dissolved in cyclic lactam monomer or its corresponding amino acid, dehydrate in vacuum, add catalyst and catalyst promoter, cast into a mould and polymerize to obtain toughened nylon.

5

In reacting extrusion process long-chain nylon dissolved in cyclic lactam monomer or its corresponding amino acid, which and another batch of cyclic lactam monomer or its corresponding amino acid containing catalyst promoter are transferred separately into a mixer for mixing with metering pumps. Then the 10 mixture is fed into an extruder (single or double screw extruder) and the extruded product is toughened nylon.

In hydrolysis polymerization process, long-chain nylon and cyclic lactam monomer or its corresponding amino acid are added into a polymerization kettle; 15 hydrolysis polymerization is carried out at high temperature (for example 200-250°C) while stirring. Raise the viscosity of resin in vacuum. Then discharge under pressure after 0.2-6 hours and cut toughened nylon into pellets. Besides, high molecular weight nylon may be obtained by further solid phase condensation polymerization of the toughened nylon.

20

In case  $\omega$ -amino acid is used as matrix nylon monomer, toughened nylon is prepared by solid phase polymerization. The detail steps are as follows: add long-chain nylon to  $\omega$ -amino acid and conduct condensation polymerization at 200-250°C, then conduct solid phase condensation polymerization at 150-200°C 25 and in vacuum to further increase molecular weight. After 6-24 hours toughened nylon is obtained.

In these processes mentioned above the kinds and amounts of catalyst and catalyst promoter are readily defined by technical personnel skilled in the art. 30 Among the preferred catalysts are sodium hydroxide, potassium hydroxide, sodium alkoxide and Grignard reagent, and among the preferred catalyst promoters are

isocyanate, acyl amide, acyl chloride, carbonate, polyester and urea, particularly such as 2,4-tolune diisocyanate (TDI), acetyl acetamide, acetyl chroride, dimethyl carbonate and polyethylene telephthalate (PET). It is preferred that the amount of catalyst is 0.0005-10% (wt.) and the amount of catalyst promoter is 0.005-4%(wt),  
5 or 0.02-2% (wt.) better, based on the weight of cyclic lactam monomer or its corresponding amino acid. In hydrolysis polymerization the amount of adding water is 10-100% (wt.), based on the weight of cyclic lactam monomer or its corresponding amino acid.

10 In the preparation processes mentioned in the invention, the time to add long-chain nylon to cyclic lactam monomer or its corresponding amino acid depends on actual polymerization process adopted. In casting process long-chain nylon has to be dissolved in cyclic lactam monomer or its corresponding amino acid before cast polymerization. In reacting extrusion process, long-chain nylon is  
15 dissolved in a part of cyclic lactam monomer or its corresponding amino acid firstly, and another part of cyclic lactam monomer or its corresponding amino acid is then added during reacting extrusion. In hydrolysis polymerization in a reaction kettle, long-chain nylon may be dissolved in cyclic lactam monomer or its corresponding amino acid before polymerization or be directly added during hydrolysis  
20 polymerization.

An aspect of the invention is directed to a matrix nylon toughened by long-chain nylon. The long-chain nylon used as toughening agent is dissolved in melted cyclic lactam monomer or its corresponding amino acid, so that long-chain  
25 nylon is dispersed into polymer system as single molecules and a homogenous phase system is formed. In Figure 4 to 6, there is only one melting peak in the deferential scanning calorimetry (DSC) spectrum of the toughen nylon system prepared by this invention, but there are two melting peaks in the deferential scanning calorimetry (DSC) spectrum of the mixture system of matrix nylon and  
30 long-chain nylon, which confirms the homogenous nature of toughened nylon system. From scanning electronic microscope photos shown in Figure 1 to 3, it is

obvious that the crystal morphology of toughened nylon is different from that of normal nylon, which greatly improves the toughness and breaking elongation of matrix nylon.

5 Another aspect of the invention is directed to the preparation of homogenous solution suitable for the casting and reacting extrusion processes of nylon preparation by using long-chain nylon as toughening agent as it is dissolvable in cyclic lactam monomer or its corresponding amino acid. Rubber is often used to toughen nylon in much prior art, but as rubber is essentially not dissolvable in  
10 cyclic lactam monomer, only screw excursion process is suitable for the preparation of nylon toughened by rubber. Besides a solubilizer must be added to improve the compatibility of rubber with matrix nylon.

The following examples intend to give further explanation for this invention.  
15 However it should be remind that this invention is by no means restricted by these examples. The parts and percentages in these examples are based on weight, unless specified otherwise.

#### Example 1 (Casting)

20 Dissolve 8 parts of nylon-1212 in 92 parts of melted hexanolactam monomer while stirring and dehydrate in vacuum for 0.5 hour; add 0.2% of sodium hydroxide (based on the weight of monomer), dissolve and dehydrate in vacuum to obtain sodium amide used as catalyst; raise temperature to 140°C and add 0.4% of 2,4-tolune diisocyanate (TDI); immediately transfer into a mould preheated at  
25 165°C and then conduct polymerization in an oven at 170°C to obtain casting nylon-6 toughened by nylon -1212. The mechanical properties of toughened nylon system are listed in Table 1 and its electronic microscope photos and deferential scanning calorimetry (DSC) spectrums are shown in Figure 1 and 4 respectively.

#### Example 2 (Extrusion)

Add 10 parts of powder nylon-1212 to 70 parts of hexanolactam monomer in

a reaction kettle and dissolve at 140°C; dehydrate in this stainless steel kettle in vacuum; add 0.2% of sodium hydroxide (based on the weight of monomer) and continue to dehydrate in vacuum; in another reaction kettle add 20 parts of hexanolactam monomer and 0.4% of TDI (based on the weight of monomer) and  
5 dehydrate in vacuum; transfer the contents of two reactors into a double screw extruder with metering pumps; adjust the temperature of polymerization section at 240°C and control the speed of screw so that the residence time of material in screw is 1-3 minutes. The product is reacting extrusion nylon-6 toughened by nylon-1212. The mechanical properties of toughened nylon system are listed in Table 1 and its  
10 electronic microscope photo is shown in Figure 2.

Example 3 (Solid phase condensation polymerization)

Add 5 parts of nylon-46 chip to 50 parts of  $\omega$ -amino butanoic acid and 45 parts of  $\omega$ -amino hexanoic acid; conduct condensation polymerization at 230°C; 15 then carry out solid phase condensation polymerization at 160°C to further increase its molecular weight; obtain co-condensation nylon 4/6 modified by nylon-46 after 24 hours. The mechanical properties of toughened nylon system are listed in Table 1

20       Example 4 (Hydrolysis)

Add 10 parts of nylon-1012 and 9 parts of deionized water to 90 parts of N-methyl hexanolactam monomer; raise pressure to 12 MPa and temperature to 230°C; conduct hydrolysis polymerization for 4 hours; then depressurize and continue polymerization in vacuum for 2 hours; discharge by filling nitrogen and  
25 cut product into pellets to obtain poly(N-methyl hexanolactam) toughened by nylon-1012. The mechanical properties of toughened nylon system are listed in Table 1

Example 5 (Casting)

30       Dissolve 6 parts of nylon-3436 in 94 parts of butanolactam while heating; dehydrate for 30 minutes in vacuum; add 0.0005% of potassium hydroxide (based

on the weight of monomer) and further dehydrate for 20 minutes; when the temperature of solution reaches 120°C add 0.02% of acetyl acetamide (based on the weight of monomer) and stir uniformly; immediately transfer into a mould preheated at 180°C and then put into an oven at 180°C for polymerization to obtain 5 nylon-4 toughened by nylon-3436. The mechanical properties of toughened nylon system are listed in Table 1

Example 6 (Casting)

Dissolve 2 parts of poly(telephthaloyl-2,2,4-trimethyl hexamethylene diamine) 10 in 98 parts of melted butanolactam monomer while stirring; dehydrate in vacuum for 0.5 hour; then add 2% of potassium hydroxide (based on the weight of monomer) and dehydrate and dissolve in vacuum to obtain sodium amide that is used as catalyst; raise temperature to 160°C and add 2% of acetyl chloride (based on the weight of monomer); immediately transfer into a mould preheated at 200°C; 15 conduct polymerization in an oven at 200°C to obtain casting nylon-4 toughened by poly(telephthaloyl-2,2,4-trimethyl hexamethylene diamine). The mechanical properties of toughened nylon system are listed in Table 1.

Example 7 (Casting)

20 Dissolve 25 parts of nylon-8 in 75 parts of octanolactam while heating; dehydrate in vacuum for 30 minutes; add 5% of sodium alkoxide (based on the weight of monomer) and further dehydrate for 20 minutes; when the temperature of solution reaches 200°C add 4% of urea (based on the weight of monomer) and stir uniformly; immediately transfer into a mould preheated at 250°C and then put into 25 an oven at 250°C for polymerization to obtain casting nylon-8 toughened by nylon-8. The mechanical properties of toughened nylon system are listed in Table 1.

Example 8 (Casting)

30 Dissolve 15 parts of poly(3-t-butyl-hexanedioyl heptamethylene diamine) in 85 parts of nonanolactam while heating; dehydrate for 30 minutes; add 10% of

Grignard reagent (based on the weight of monomer) and further dehydrate for 20 minutes; when the temperature of solution reaches 130°C add 4% of TDI (based on the weight of monomer) and stir uniformly; immediately transfer into a mould preheated at 150°C and then put into an oven at 150°C for polymerization to obtain 5 casting nylon-9 modified by poly(3-t-butyl-hexanedioyl heptamethylene diamine). The mechanical properties of toughened nylon system are listed in Table 1.

#### Example 9 (Hydrolysis)

Add 45 parts of nylon-13 chip to 55 parts of N-n-octyl nonanolactam 10 monomer and dissolve at 140°C; add 25 parts of deionized water and conduct hydrolysis polymerization at 250°C and 20 MPa; depressurize after a half hour and dehydrate in vacuum; continue polymerization to further increase viscosity; after 6 hours discharge with pressure and cut the product into pellets to obtain 15 poly(N-n-octyl nonanolactam) toughened by nylon-13. The mechanical properties of toughened nylon system are listed in Table 1.

#### Example 10 (Hydrolysis)

Add 30 parts of nylon-24 chip to 70 parts of decanolactam monomer and dissolve at 140°C; add 70 parts of deionized water and conduct hydrolysis 20 polymerization at 200°C and 10 MPa; depressurize after 6 hours and dehydrate in vacuum; continue polymerization to further increase viscosity; after 0.2 hours discharge with pressure and cut product into pellets to obtain hydrolysis condensation nylon-10 toughened by nylon-24. The mechanical properties of toughened nylon system are listed in Table 1.

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#### Example 11 (Casting)

Dissolve 10 parts of co-condensation nylon 6/7 resin in 90 parts of decanolactam while stirring; dehydrate in vacuum for 0.5 hour; add 0.02% of potassium hydroxide (based on the weight of monomer), dissolve and dehydrate in 30 vacuum to prepare sodium amide that is used as catalyst; raise temperature to 140°C and add 0.005% of TDI (based on the weight of monomer); immediately

transfer into a mould preheated at 165°C and conduct polymerization in an oven at 170 °C to obtain casting nylon-10 toughened by co-condensation nylon 6/7. The mechanical properties of toughened nylon system are listed in Table 1.

5       Example 12 (Extrusion)

Add 15 parts of nylon 6T powder to 100 parts of dodecanolactam monomer in a reactor kettle and dissolve at 100°C; dehydrate in vacuum in the stainless steel kettle; add 3% of sodium hydroxide (based on the weight of monomer) and further dehydrate in vacuum; in another reactor add 20 parts of dodecanolactam monomer  
10 and 2.5% of dimethyl carbonate (based on the weight of monomer) and dehydrate in vacuum; add the contents of two reactors into a double screw extruder with metering pumps; adjust the temperature of polymerization section at 250°C and control the speed of screw so that the residence time of material in screw is 0.5-2 minutes to obtain reacting extrusion nylon-12 toughened by nylon 6T. The  
15 mechanical properties of toughened nylon system are listed in Table 1.

Example 13 (Solid phase condensation)

Add 10 parts of co-condensation nylon 10/12 chip to 50 parts of  $\omega$ -amino hexanoic acid and 50 parts of  $\omega$ -amino octanoic acid; conduct condensation  
20 polymerization at 200°C; then carry out solid phase condensation polymerization at 150°C to further increase molecular weight; thus after 12 hours co-condensation nylon 6/8 modified by co-condensation nylon 10/12 is obtained. The mechanical properties of toughened nylon system are listed in Table 1.

25       Example 14 (Extrusion)

Add 20 parts of co-condensation nylon 20/34 to 100 parts of N-t-butyl dodecanolactam monomer in a reactor kettle and dissolve at 120°C; dehydrate in vacuum in this stainless steel kettle; add 0.002% of sodium hydroxide (based on the weight of monomer) and continue to dehydrate in vacuum; in another reactor add  
30 20 parts of N-t-butyl dodecanolactam monomer and 0.01% of PET (based on the weight of monomer) and dehydrate in vacuum; add the contents of two reactors into

a single screw extruder with metering pumps; and adjust the temperature of polymerization section at 220°C and control the speed of screw so that the residence time of material in screw is 5-7 minutes to obtain reacting extrusion poly(N-t-butyl dodecanolactam) toughened by co-condensation nylon 20/34. The 5 mechanical properties of toughened nylon system are listed in Table 1.

Example 15 (Solid phase condensation)

Add 5 parts of nylon 1010 chip to 95 parts of  $\omega$ -amino undecanoic acid monomer; conduct condensation polymerization at 250°C and then carry out solid 10 phase condensation polymerization in vacuum at 200°C to further increase molecular weight; after 6 hours nylon 11 toughened by nylon 1010 is obtained. The mechanical properties of toughened nylon system are listed in Table 1.

Example 16 (Casting)

15 Dissolve 8 parts of nylon-66 in 92 parts of melted hexanolactam monomer while stirring and dehydrate in vacuum for 0.5 hour; add 0.2% of sodium hydroxide (based on the weight of monomer), dissolve and dehydrate in vacuum to obtain sodium amide used as catalyst; raise temperature to 140°C and add 0.03% of 2,4-tolune diisocyanate (TDI); immediately transfer into a mould preheated at 20 165°C and then conduct polymerization in an oven at 170°C to obtain casting nylon-6 toughened by nylon-66. The mechanical properties of toughened nylon system are listed in Table 1.

Table 1

Ex.	Matrix nylon monomer	Long-chain nylon	Tensile strength (MPa)	Breaking elongation (%)	Notched impact strength (J/m)	Impact strength at -40°C (J/m)
1	Hexanolactam	Nylon-1212	45	546	236	215
2	Hexanolactam	Nylon-1212	61.5	430	189	153
3	ω-amino butanoic acid ω-amino hexanoic acid	Nylon-46	64	173	121	103
4	N-methyl hexanolactam	Nylon-1012	52	720	459	423
5	Butanolactam	Nylon-3436	51	432	323	279
6	Butanolactam	Poly(telephthaloyl-2, 2,4-trimethyl-hexamethylene diamine)	53	315	249	207
7	Octanolactam	Nylon-8	47	470	537	523
8	Nonanolactam	Poly(3-t-butyl-hexamethylenediyl heptamethylene diamine)	45	723	578	517
9	N-n-octyl nonanolactam	Nylon-13	40	780	673	638
10	Decanolactam	Nylon-24	40	780	753	724
11	Decanolactam	Co-condensation Nylon 6/7	45	670	573	552
12	Dodecanolactam	Nylon 6T	44	420	483	472
13	ω-amino hexanoic acid ω-amino octanoic acid	Co-condensation Nylon 10/12	52	453	354	323
14	N-t-butyl dodecanolactam	Co-condensation Nylon 20/34	40	820	728	709
15	ω-amino undecanoic acid	Nylon-1010	38	652	615	527
16	Hexanolactam	Nylon-66	55	532	213	195
The properties of several nylons in prior art						
	Nylon-4		---	36	--	--
	Nylon-6		60-65	30	50-70	40-60
	Nylon-9		58-65	182	250-300	--
	Nylon-11		45-55	10-27	250-350	--

Note: The determination procedures for various properties in the Table are ASTM-D638 for tensile strength and breaking elongation and ASTM -D256 for notched impact strength.